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COGNITIVE PERFORMANCE, SLEEP QUALITY AND MOOD DURING DEEP OXY-H--ETC(U)
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COGNITIVE PERFORMANCE, SLEEP QUALITY AND MOOD DURING DEEP OXY-HELIUM DIVING

Vivien J. Lewis
Alan D. Baddeley
MRC Applied Psychology Unit, Cambridge

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ABSTRACT

This study forms part of a series of simulated saturation oxyhelium dives, examining physiological and psychological changes in man in high pressure conditions. A series of five dives are reported, lasting between 18 and 26 days, and reaching maximum depths of between 300 msw and 540msw. Tests of cognitive functioning, including associative and short term memory, arithmetic ability, perceptual speed, spatial manipulation, grammatical reasoning and semantic processing, were administered to well-practiced subjects prior to each dive, at maximum depth and again during decompression. Self-report measures of sleep and mood questionnaires were administered for a period extending from one week before each dive commenced until at least one week after the dive was completed. The results indicate significant impairments in all performance tasks at maximum depth, except for the tests of associative memory and grammatical reasoning. A significant reduction in sleep and decrease in the subjective level of alertness was found at maximum depth for all dives. Correlational analyses suggest that it is unlikely however that these are responsible for the clear decrements observed in cognitive performance at depth.

CONTENTS

INTRODUCTION

1. In order to survive, a diver must breathe gas at a pressure equivalent to the surrounding water. If that gas is pure oxygen, he is likely to suffer oxygen poisoning leading to convulsions and death if he operates at a depth exceeding 15 - 20 m. If he breathes air, then at depths exceeding 30 m he is likely to show the symptoms of nitrogen narcosis, a drunkenness produced by the nitrogen in the air; as a result of this, the maximum practicable working depth for an experienced air diver is in the region of 60 m, after which point performance is likely to deteriorate rapidly to a dangerous level, with dramatically increased likelihood of accident, and eventually, loss of consciousness somewhere between 90 and 120 m (Shilling, Werts and Schandelmeier, 1976).

If instead of breathing air, the diver breathes a mixture of helium and oxygen, then he is able to function at much greater depths and open sea trial dives have occurred to depths of over 600 m. Unfortunately, although oxyhelium has clear advantages over air as a breathing mixture for deep dives, it is not without problems. If a diver is compressed rapidly, he is likely to suffer from High Pressure Nervous Syndrome (HPNS) of which the symptons are nausea, dizziness and tremor. If the rate of compression is slowed down however this can be avoided, and it initially seemed likely that given slow rates of compression, oxyhelium did not impair the diver's cognitive capacities. Biersner and Cameron (1970 a) reported no significant difference between a surface control and an experimental group in a saturation dive to a simulated depth of 300 m of sea water (msw) on three tasks, associative memory, a cognitive figures test and a congnitive interference test, and although they had previously found an impairment in associative memory at 180 msw (Biersner and Cameron, 1970 b), they attributed this to psychological stress rather than to the effect of the breathing mixture. Hamilton (1976) found little or no decrement on tests of arithmetic ability, reaction time, manual dexterity, strength or time estimation when subjects were breathing either oxyhelium or a neon-oxygen mixture at pressures up to 360 msw.

Other studies however have reported varying degrees of impairment of cognitive functioning. Baddeley and Fleming (1967) observed a decrement in speed of performance on tasks involving manual dexterity and addition at a depth of only 60 msw on both open sea and dry pressure chamber dives. It seems likely however that the decrement was produced by the very rapid compression, possibly combined in the open sea dive with anxiety due to the fact that the subjects were amateurs using newly developed and relatively untried equipment. Riley (1974) showed performance deficits "directly related to task complexity" in long-term memory and cognitive function in a dive by six subjects to 135 msw, and in a later paper (Riley, 1977) reported increased reaction times and an increase in errors in arithmetic in a dive to 160 msw. However, he found no differences in spatial orientation or associative memory, and the reaction time and arithmetic impairments abated over time. Lemaire and Murphy (1976) showed decrements in performance at 610 msw on a number ordination test and on visual choice reaction time. Finally Carter (1979) has shown impairment in perceptual speed and number facility in a dive to 527 msw. He observed however that performance on an associative memory task actually improved at depth. The pattern of results therefore is somewhat equivocal.

Recent research has paid more attention to subjective reports with a view to investigating the possible role of sleep loss, fatigue and particularly anxiety in the observed performance of the diver. A study by Townsend and Hall (1978) examined the effects on sleep, mood and rated fatigue of a 14-day open sea dive to 260 msw. They found a considerable reduction in sleep, with an associated increase in fatigue and loss of "psychological vigour", together with a higher level of total mood disturbance throughout the dive. They suggest that these effects were probably due to demanding work schedules and noise problems.

The present study forms part of a research programme being carried out at the Admiralty Marine Technology Establishment at Alverstoke. In addition to measures of performance, the project examines the effects of deep oxyhelium dives on the nervous system of the diver, his respiratory physiology, haematology, metabolism, bone radiology and biochemistry. (See Hempleman et al., 1978; in press for further details). The dives to be described were preceded by four "work-up" dives. As far as possible, these used the same subjects as were used in subsequent dives, with the result that on most of our dives subjects were reasonably well practised beforehand. These preliminary dives involved two on air at a pressure equivalent to three metres of sea water, one on oxyhelium at a similar depth, and one at a depth of 200 m, again breathing oxyhelium. Details of these may be found in Hempleman et al.(1978). The first dive to be reported is therefore Dive 5; we maintain the original dive numbering in the present report so as to facilitate cross-reference to the many other non-psychological studies that were carried out on these dives (Hempleman et al , 1978; in press).

The present study attempted to answer three questions. (1) Is cognitive performance impaired when breathing oxyhelium at high pressure? If so, what functions show a decrement? (2) Are there mood changes at high pressure, and if so how are these related to any observed cognitive impairment? (3) Are there alterations in sleep pattern under high pressure? If so how are these related to cognitive and mood changes at depth?

METHOD

2. Five dives will be reported, each involving two experienced subjects. Brief details of the dives are given in Table 1.

Design

3. An investigation of this sort presents major problems of experimental design. For reasons of safety, a programme of this kind must begin at a relatively shallow depth, with depth increasing on later dives if all goes well. It is not therefore practicable to counterbalance the order in which dives at a given depth are made. The second problem is that each dive is extremely expensive (current cost approximately £100,000 per dive). Since each dive involves only two subjects, the experimental sample size is inevitably small. Consequently many of the earlier studies were based on only two or three subjects. The present study samples a total of seven different subjects participating in ten man-dives; an unacceptably small sample in the case of many projects, but a large sample by the standards of deep diving trials.

In order to maximise the amount of information collected from each dive, four testing sessions were used. The first session occurred in advance of the dive itself and involved either training the subject, or if, as in the case of all but one dive, he had been tested before, served as a revision session. It was followed by three test sessions, the first of which took place about a week before the start of the dive, the second of which occurred approximately 24 hours after reaching maximum depth, while the third occurred during the decompression phase when the subject reached a depth at which any impairments should be minimal (see Table 1 for details). From the viewpoint of an ideal design, it might have been better to have delayed this last test until the subjects were back at normal atmospheric pressure. This was not however deemed advisable. When a subject has been

Table 1. Characteristics of the five dives+

Dive	Subject No	Compression Rate	Max Depth	Timing of Testing Sessions: Surface (Days before dive)	Depth	Decompression
5	1 2	1m/min	300m	10	day 6 300m	day 14 140m
6	3 4	1m/min (1 stop)	300m	10	day 4 300m	day 12 135/140m
7	3 5	6m/hr (stops)	420m	10	day 8 370m*	day 20 140m
8	1 4	6m/hr (stops)	420m	10	day 9 420m	day 20 132m
9	6 7	5m/min (stops)	540m	6	day 6 540m	day 22 114m

* dive 7 was held at 370m for 2 days during compression stage

\+ Details of dives 1-4 can be found in a report by Hempleman et al, 1978.

cooped up in a tiny chamber for anything up to a month, and is finally back at surface pressure again, it seemed likely that his attention would be much more concerned with getting out of the chamber than with completing performance tests.

Of the five dives that will be reported, two of the dives (5 and 6) were to 300 msw, two (7 and 8) were to 420 msw, although for one of these testing took place at 370 msw, and one dive (9) was to 540 msw. All dives were carried out in an oxyhelium atmosphere in a laboratory chamber at the Admiralty Marine Technology Establishment in Alverstoke, and the duration of the dives varied from 18 to 26 days. Normally sleep and mood testing began one to two weeks prior to each dive, and continued until about one week after completion of the dive.

Subjects

4. The subjects in all but dive 9 were young male volunteers, working at or associated with the Admiralty Marine Technology Establishment. All subjects had medical examinations prior to each dive, and were in good physical condition. Subjects in dive 9 were young male commercial divers paid for participation.

5. Testing Procedure

a. Mood and Sleep Questionnaires A sleep questionnaire was completed every morning by each subject, beginning normally one to two weeks prior to the dive, and continuing until one to two weeks after the end of the dive. The questionnaire consisted of nine items, seven of which enquired about general sleep quality, dreams, number of times the subject woke up during the night, etc; one item required the subject to make a perpendicular mark across a 10 cm line, the two ends of which were labelled "worst possible" (sleep) and "best possible" (sleep), according to the subject's own estimation of the quality of the preceding night's sleep, and the last item enquired about any factors that might have affected general sleep quality.

The "mood" questionnaires were completed every morning and every evening. They consisted of 18 pairs of bipolar adjectives describing different dimensions of mood, eg tense-relaxed, antagonistic-friendly, and again took the form of a horizontal 10cm line, across which the subject was required to make a perpendicular mark indicating how he felt on that particular dimension at that particular time. This visual analogue scale was derived from a technique originally devised by Norris (1971), and later amended by Herbert, Johns and Dore (1976).

b. Performance Tests The performance tests were administered in a battery, which lasted about two hours. Subjects were normally tested twice prior to each dive (surface control), once at maximum depth (except in dive 7, where depth testing occurred during a two day stop at 370m), and again during decompression, between 114m and 140m. Tests at depth occurred some hours after arriving at that depth so as to allow any temporary HPNS symptoms to dissipate.

The battery consisted of the following tests (typically administered in this order): visual search 4-letter task, adding, visual search 2-letter task, paired-associate memory, AB sentence checking, visual search repeated letter task, Stroop control and colour tasks, visual search 6-letter task, manikin test, number similarities, semantic processing (dives 7, 8 and 9 only) and short term memory. These tests cover a wide range of human abilities and were derived partly from earlier studies by Reilly and

Cameron (1968), whose tests formed the basis of the SINBAD battery used by the U S Navy, and partly from tests used previously in studies concerning the effects of stress on performance by the MRC Applied Psychology Unit, and the MRC Perceptual and Cognitive Performance Unit.

c. Adding This test lasted 15 min, consisting of three consecutive 5-min periods. The subject was presented with a sheet which had 125 columns of five 2-digit numbers, arranged in five rows of 25 columns, he added up as many columns as possible in the 15 min period, marking his answer sheet when 5 min and 10 min had elapsed. (Wilkinson and Stretton, 1971).

d. Paired Associate Memory The subject was given one minute to memorize five 2-digit numbers, each number associated with a particular word. After an interval, usually filled with the AB sentence checking task, the subject was presented with the words in a different order, and given one minute to recall the appropriate number associated with each of the five words (Reilly and Cameron, 1968).

e. Grammatical Reasoning (AB sentence checking) This was a verbal reasoning test in which the subject assessed the truth or falsity of sentences describing the order of a letter pair following the sentence. For example: A follows B - AB (false); B is not preceded by A - BA (true). The subject was required to check as many sentences as possible in 2 min (Baddeley, 1968).

f. Stroop Tasks The Stroop control and colour tasks lasted 3 min each. In the Stroop control task the subject was presented with rows of colour names printed in black, and required to put a line through the colour name in a particular row which was the same as the first colour name in that row. In the colour task the subject was presented with rows of colour names printed in different colours. His task was to read the first word in each row and to cross out the item in that row which was printed in that ink colour, regardless of what colour name that was. The colour task involved a conflict between name and ink colour, whereas in the control task ink colour was always black, and hence was less likely to conflict with the colour name (Biersner and Cameron, 1970 a).

g. Manikin Test The Manikin test lasted 5 min. Here the subject was presented with a series of stick figures representing a man holding a ball in each hand. The figure was either upright or upside-down and facing towards or away from the subject. The figure held a different coloured ball in each hand, and above it there was a ball which was the same colour as one of the balls the figure was holding. The subjects' task was to indicate whether the figure was holding the same-coloured ball in the left or right hand (Benson and Gedye, 1963).

h. Number Similarities In this task the subject must indicate with a tick or a cross whether or not a particular pair of number sequences was identical. For example:

79168 _X_ 79178

513 _✓_ 513

The subject was required to compare as many pairs of number sequences as possible in 10 min (Reilly and Cameron, 1978).

i. Semantic Processing This task measured the speed and accuracy with which a subject could access knowledge that he had already acquired. Subjects were allowed 5 min to verify as many sentences as possible, each of which was based on "common knowledge" of the world. Half the statements were obviously true, for example: US presidents hold political office, and half the statements were obviously false, for example: Bananas are often made by carpenters (Baddeley, Thomson, Lewis and Watts, In preparation).

j. Short Term Memory The subject was presented with ninety sequences of 8 digits. The digits in each sequence were spoken at a two-digit-per-second rate, and at the end of each sequence the subject was allowed 8 s to write down as much of the sequence as possible, in the order in which the digits were presented, before the next sequence occurred. This test lasted approximately 18 min.

k. Visual Search Tasks Each of the four visual search tasks lasted 2 min. In visual search "2", "4" and "6" the subject was required to look for specific 2, 4 and 6 letter sequences respectively in rows of randomly mixed-up letters. In a particular row, the specified letters need not occur consecutively, but should all occur in the given order. The subject must tick the row if the letters are present, and put a cross if they are not (Folkard, Knauth, Monk and Rutenfranz, 1976).

In the visual search repeated letter task (visual search "O") randomly mixed-up letters were presented in blocks; the subject should put a line through any consecutively repeated letters.

RESULTS

6. Adding

Figure 1 shows the mean number of sums completed in each of the 15-min tests carried out on all five dives. Analysis of variance showed a significant effect of conditions ($F_{2,10} = 28.8$, $p < .001$). Comparison between the various conditions using a Newman-Keuls Test indicated no difference between surface and decompression conditions, both of which led to reliably better performance than was observed at depth. The impairment in speed of addition was accompanied by an increase in errors at depth, with the difference between conditions being highly significant ($F_{2,10} = 42.1$, $p < .001$). Again there was no reliable difference between surface (9.1% errors) and decompression performance (8.2%), but both were significantly lower than the error rate observed at depth (17.9%).

7. Paired Associate Memory

Results of this test are shown in Figure 2. There appears to be no decrement in performance, with performance at depth being non-significantly better than under the pre-test or decompression conditions. While this test clearly suffers from the problem of a ceiling effect which constrains performance, it seems unlikely that this is masking a genuine decrement, indeed, in view of the findings of Carter (1979) who found that his subjects performed significantly better on associative memory at depth, it may be argued that the ceiling effect is masking an improvement at depth.

8. Grammatical Reasoning

The AB sentence checking task showed no significant deterioration in speed or accuracy as a function of depth. As Figure 3 shows, although there were substantial individual differences in overall level of performance on this test there was no reliable tendency for it to be influenced by condition.

Fig. 1. Mean number of addition sums completed in 15 minutes as a function of dive and condition.

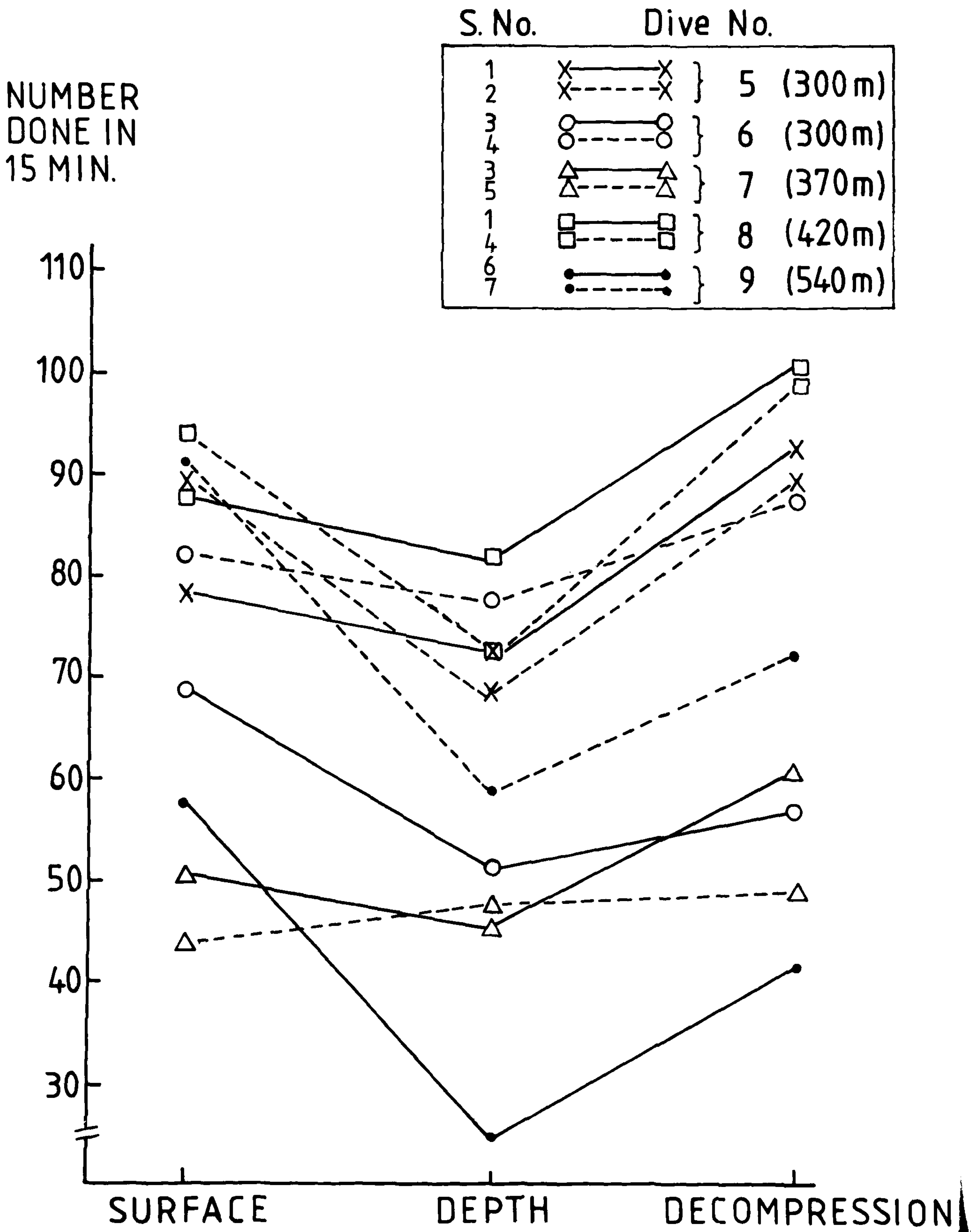


Fig. 2. Paired-associate recall as a function of dive and condition.

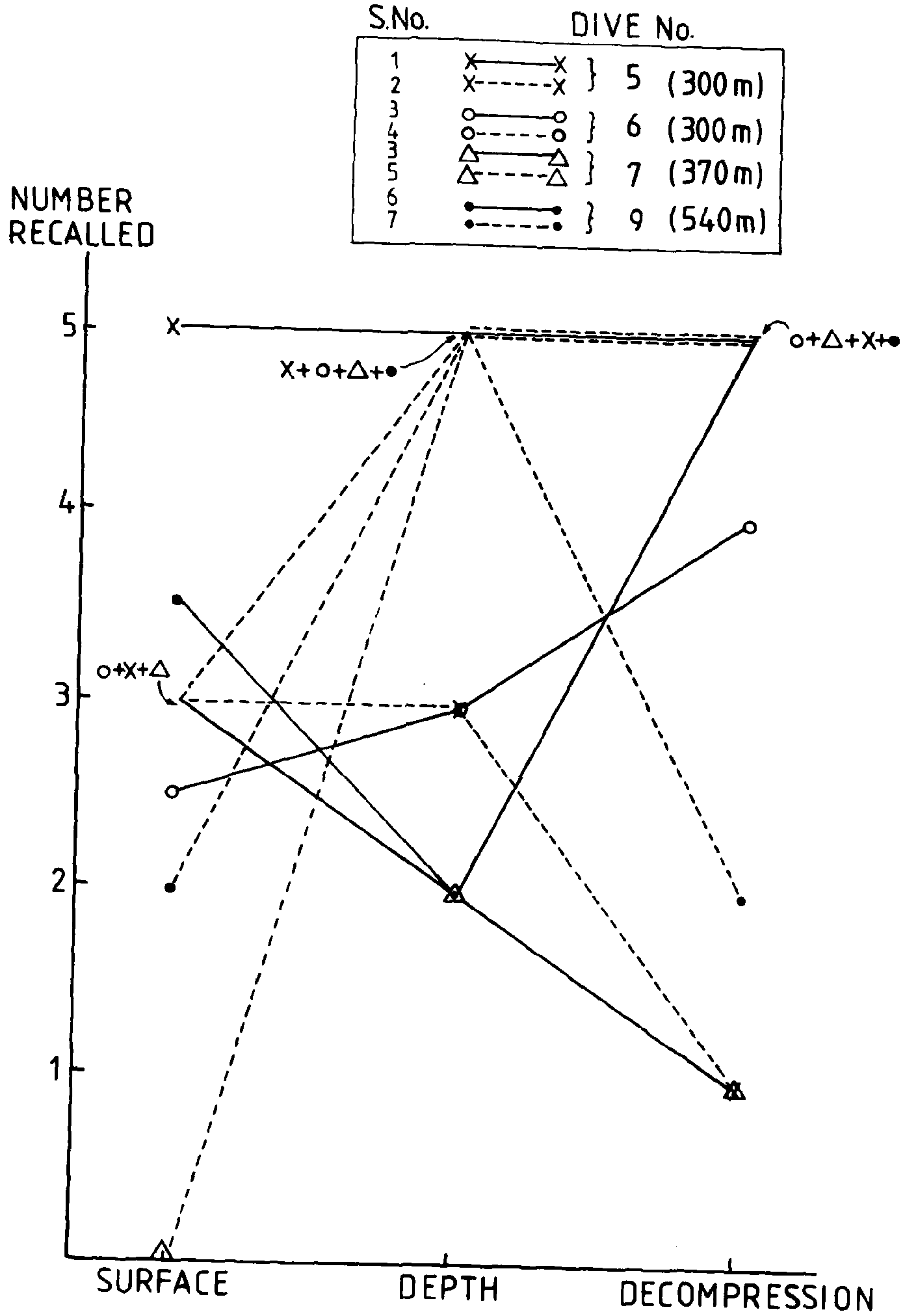
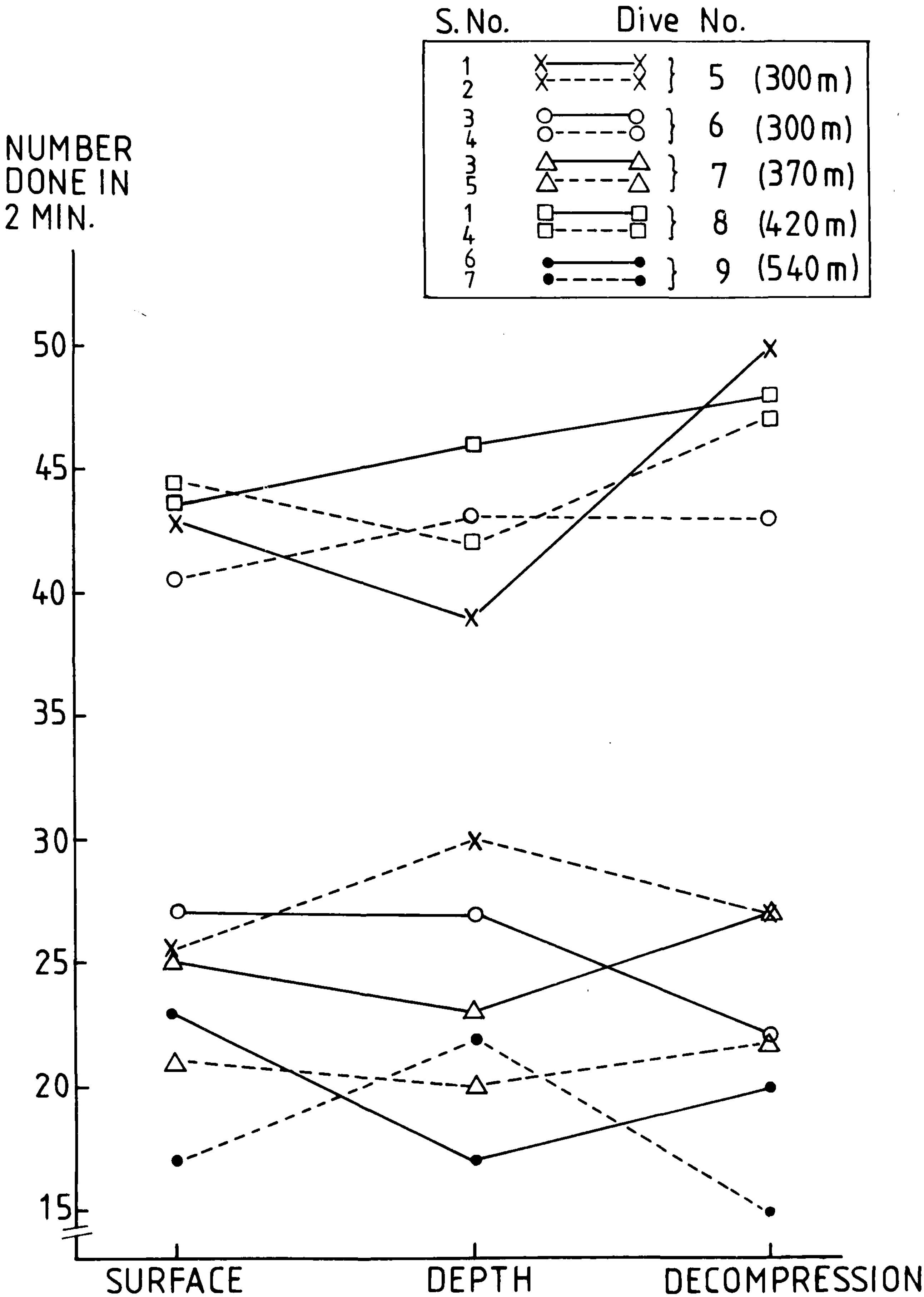


Fig. 3. Grammatical reasoning as a function of dive and condition.



9. Stroop Test

Results from both the control and conflict conditions are shown in Figure 4. Both show a clear and consistent tendency for performance to be impaired at depth (for the control condition, $F_{2,10} = 59.5$, $p < .001$; for the conflict condition $F = 59.3$, $p < .001$). In both cases, there was no reliable difference between performance on the surface and decompression conditions, both of which were significantly better than performance at depth. The difference between the control and conflict conditions however showed no sign of being greater at depth than on the surface.

10. Manikin Test

The results are shown in Figure 5, from which it is clear that although a significant amount of overall impairment was detectable at depth ($F_{2,8} = 5.95$, $p < .05$), the degree of decrement was far from dramatic in most subjects. Comparison between conditions indicated no reliable difference between performance on the surface or during decompression, both of which were reliably better than performance at depth.

11. Number Similarities

As Figure 6 shows, there was a general tendency for subjects to perform more slowly on this task at depth ($F_{2,10} = 12.9$, $p < .01$). Again depth showed significantly inferior performance to that observed on the surface or during decompression, which did not differ.

12. Semantic Processing

Although this was only introduced half way through the series, with the result that data are available for only three dives, nevertheless as Figure 7 shows, it proved very sensitive to the effects of pressure. Analysis of variance showed a highly significant difference between conditions ($F_{2,6} = 42.9$, $p < .001$); again performance at depth was reliably poorer than on either the pre-test or decompression test, which did not differ.

13. Short-term Memory

The results of the short-term memory test are shown in Figure 8, which shows a consistent but very small decrement in performance at depth ($F_{2,8} = 10.0$, $p < .01$); again surface and decompression performance did not differ, but was significantly better than that observed at depth.

14. Visual Search - Zero Load

Results of this task are shown in Figure 9. Although the effect is somewhat less consistent than that observed in some tasks, there is a reliable tendency for performance to be slowed down at depth ($F_{2,10} = 6.23$, $p < .05$). In this case, the performance at depth is inferior to that shown during decompression but not reliably different from that observed during the surface pre-test.

Fig. 4a. Performance on Stroop control as a function of dive and condition.

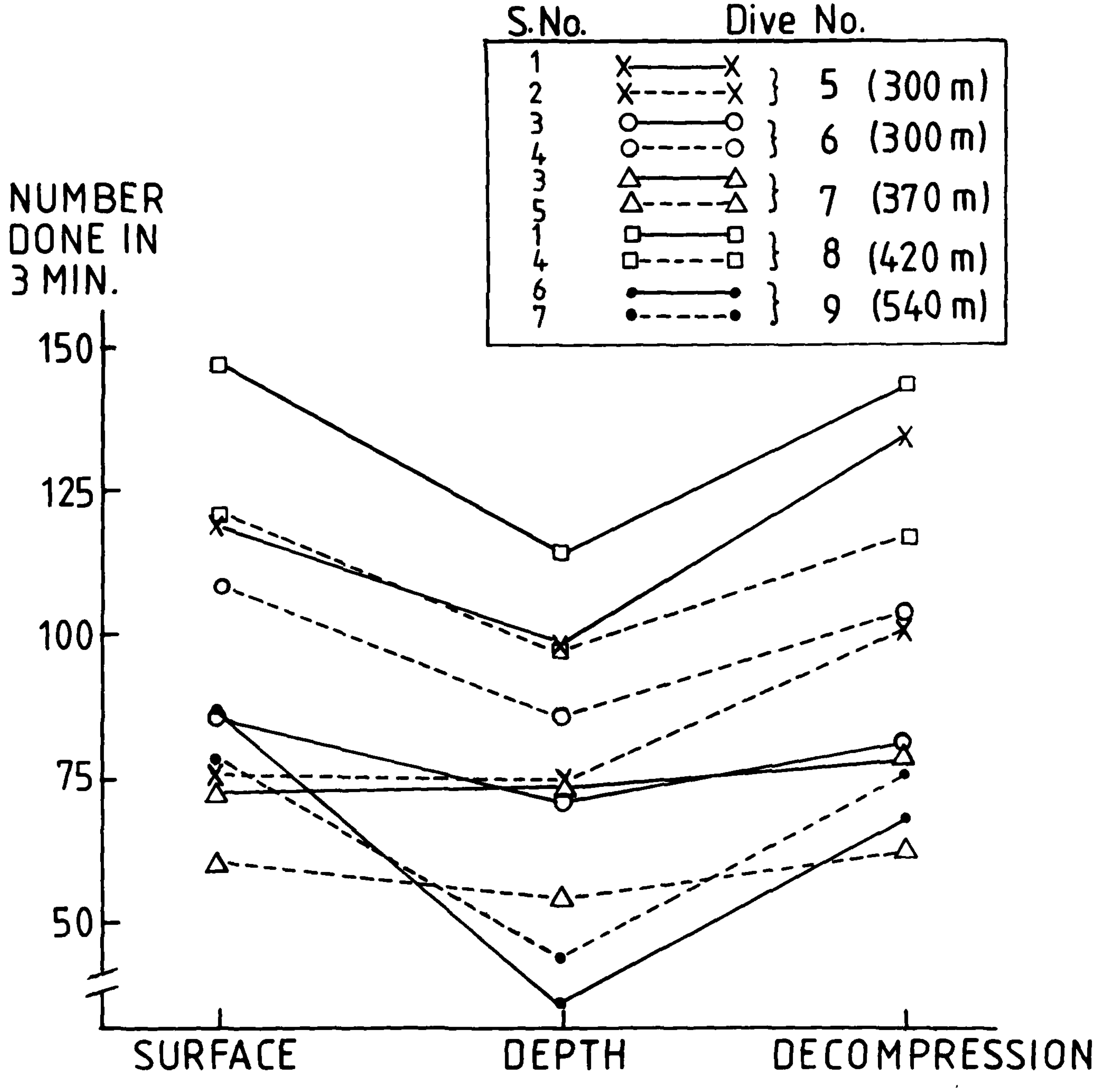


Fig. 4b. Performance on Stroop conflict task as a function of dive and condition.

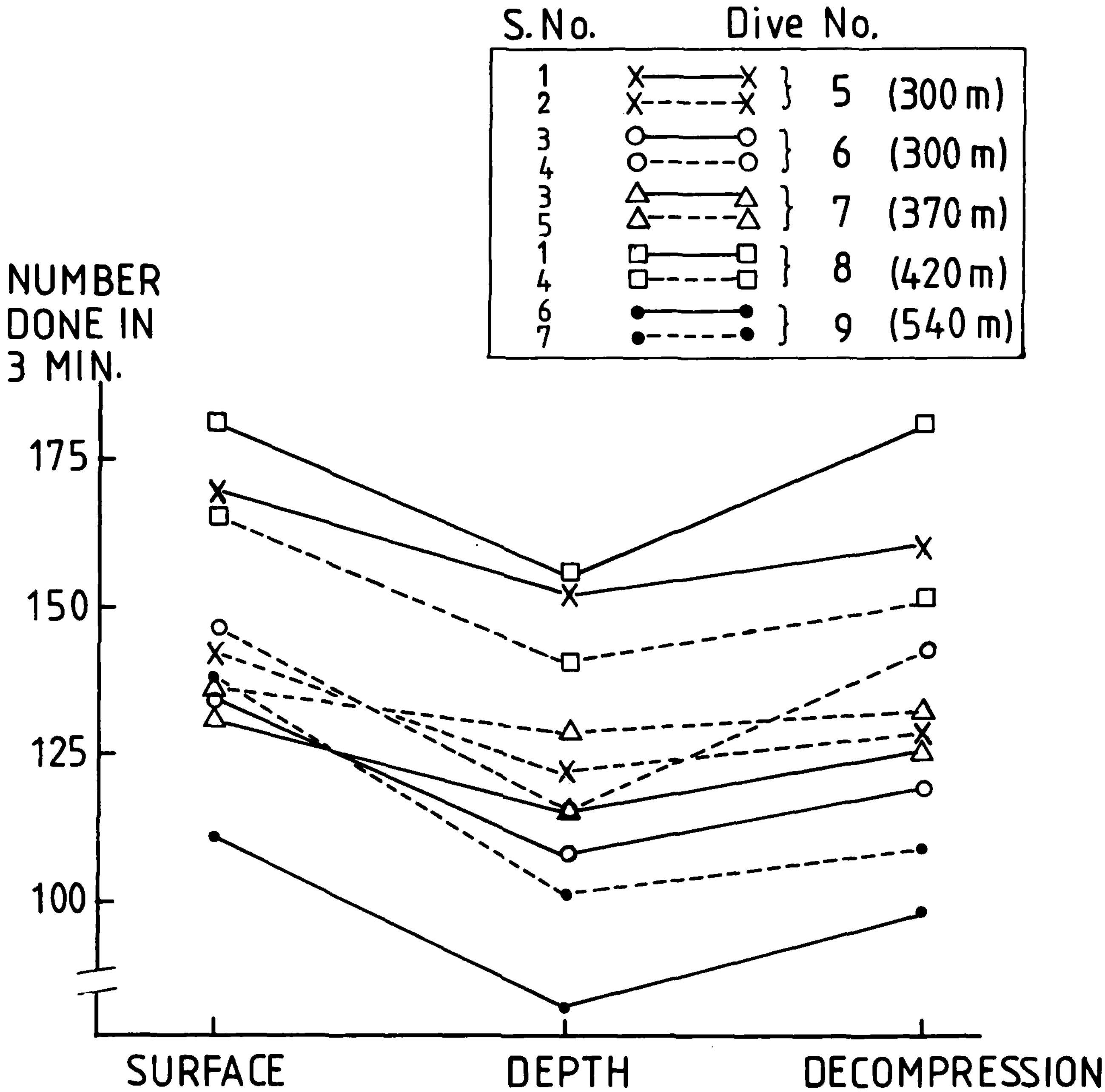


Fig. 5. Performance on the Manikin test as a function of dive and condition.

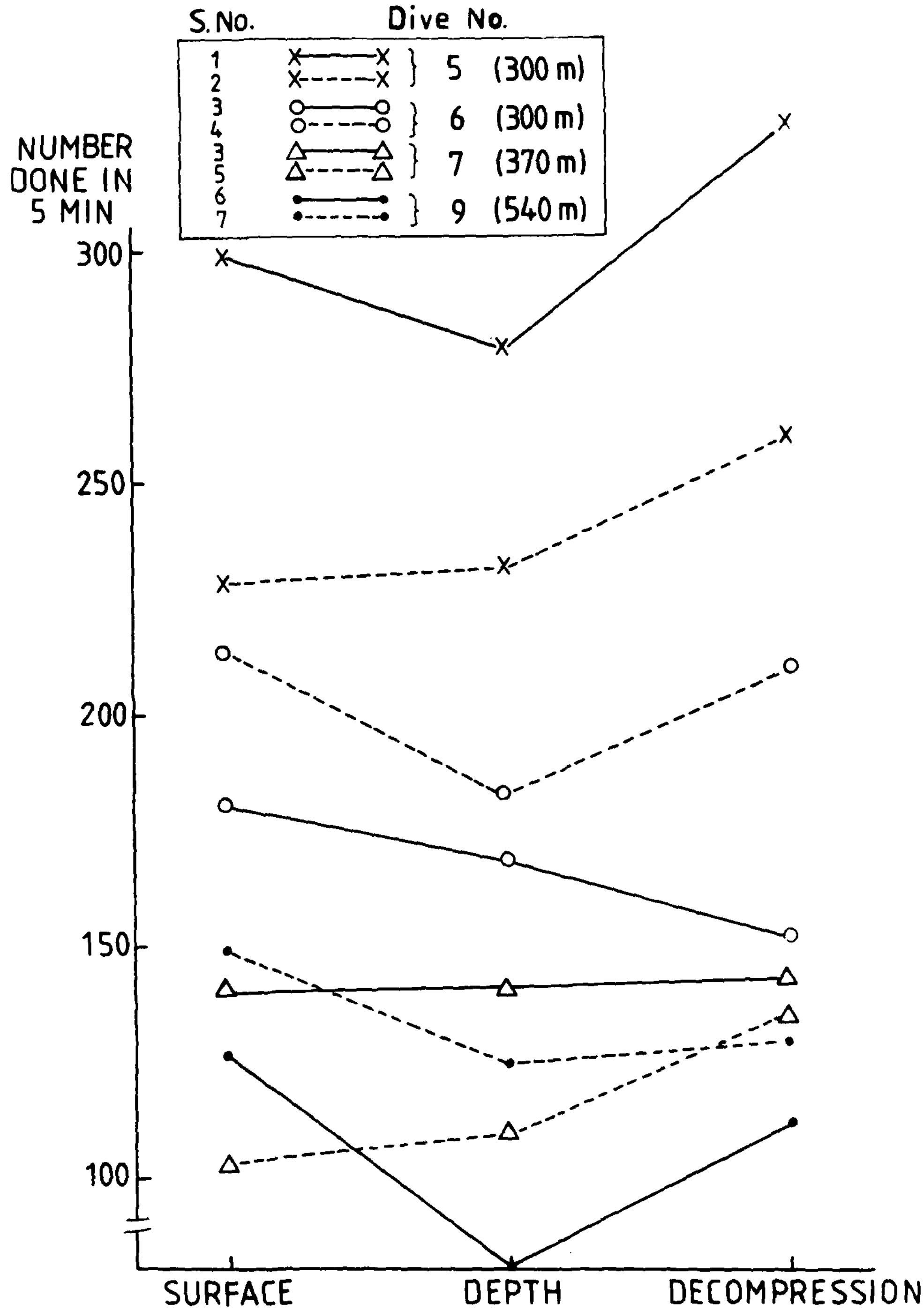


Fig. 6. Performance on the number similarities test as a function of dive and condition.

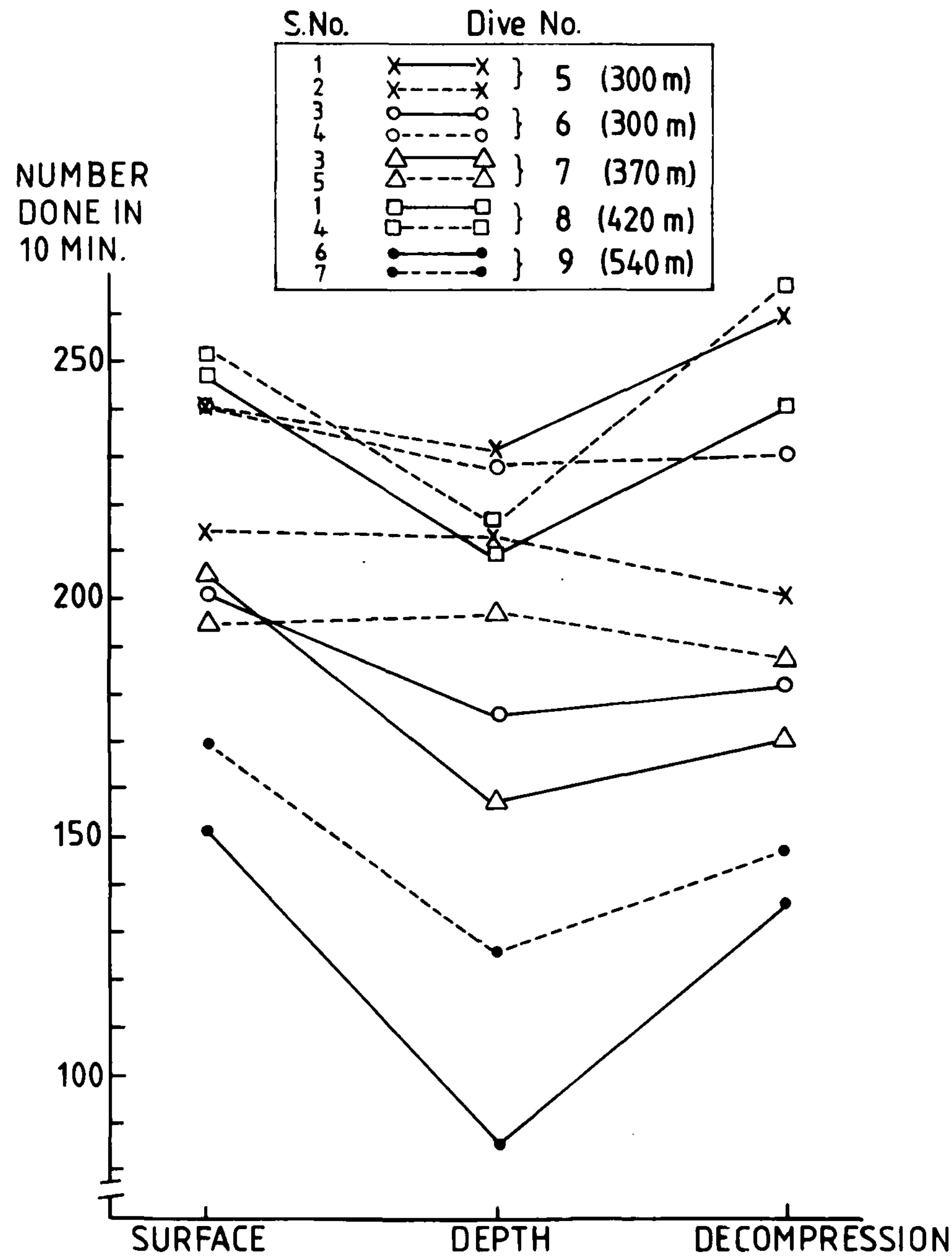


Fig. 7. Semantic processing as a function of dive and condition.

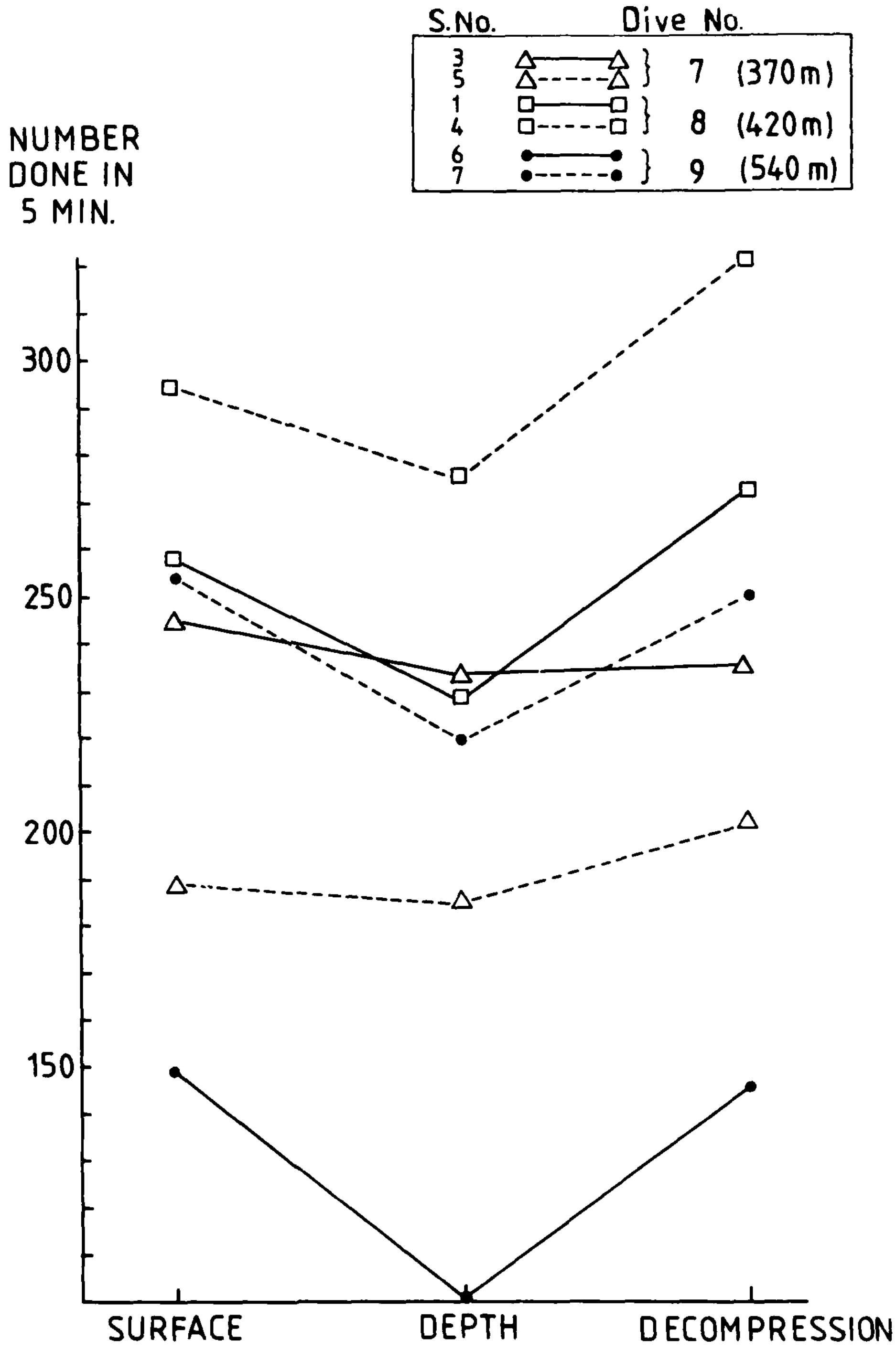


Fig. 8. Immediate memory for eight-digit sequences as a function of dive and condition.

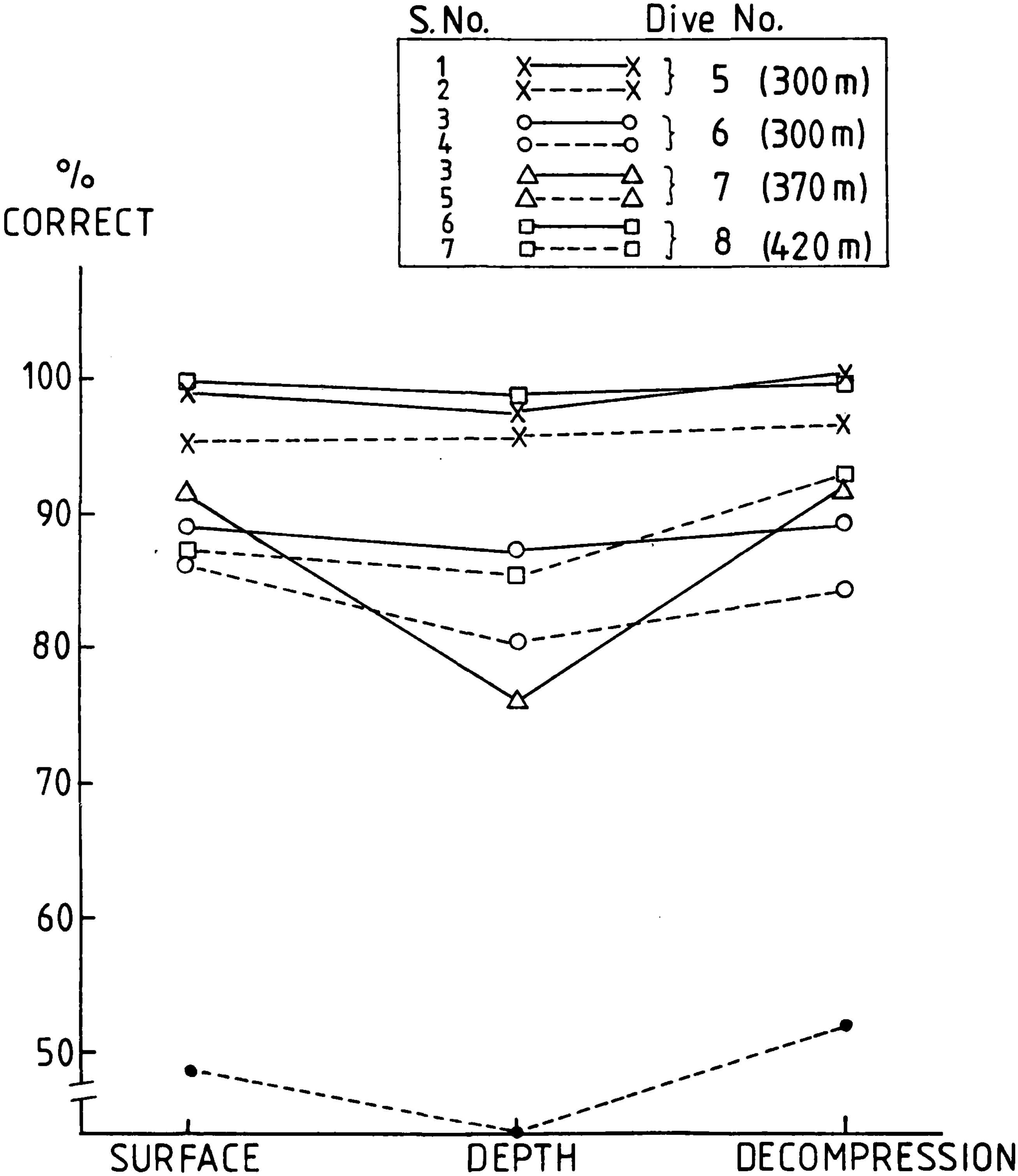
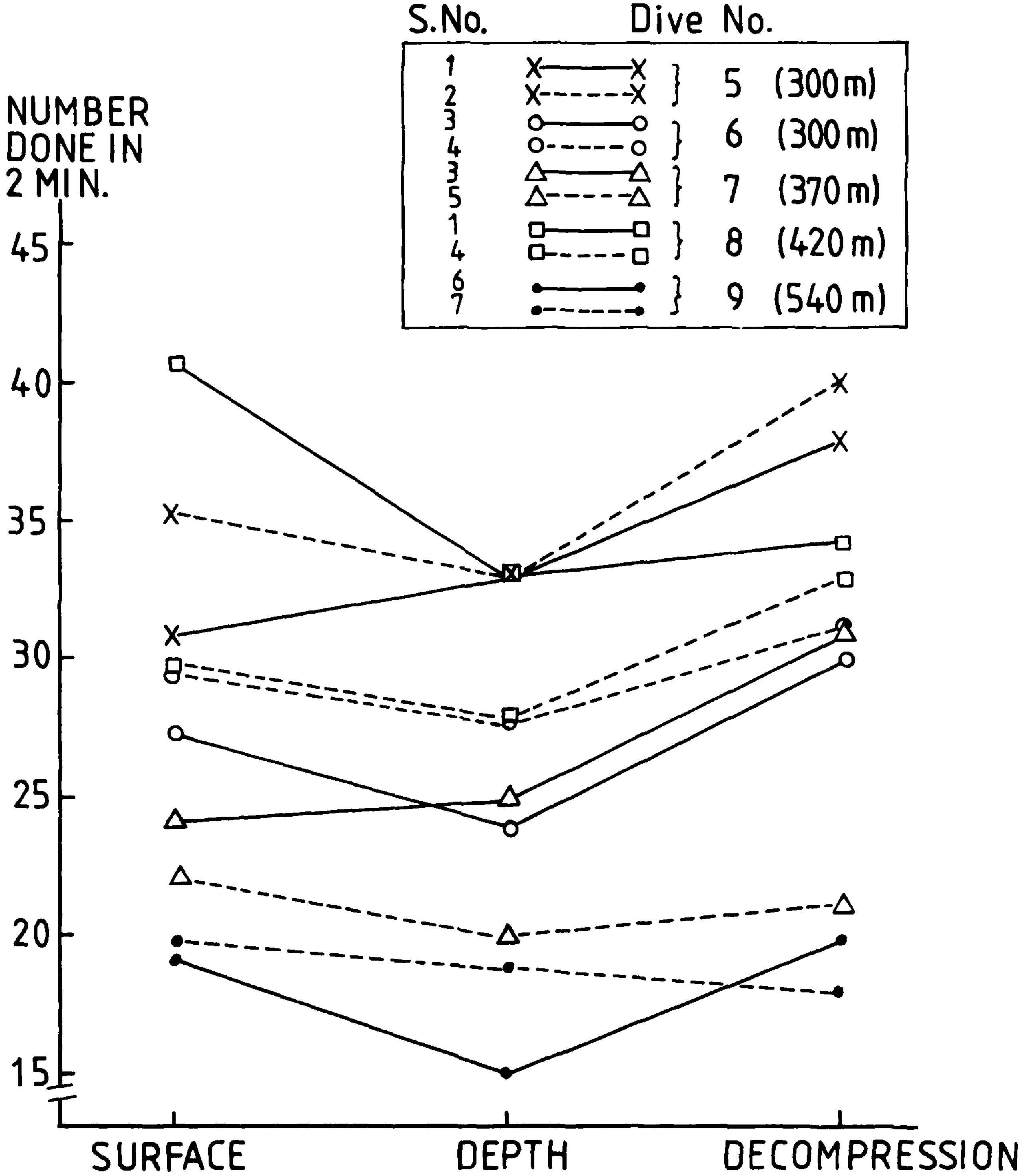


Fig. 9. Speed of searching for repeated letters as a function of dive and condition.



15. Visual Search for 2, 4 and 6 Items

The pattern of performance did not differ substantially as a function of number of items being searched for, and consequently data from the three conditions were combined. The results are shown in Figure 10 from which it is clear that there is a general and reliable tendency for performance to be inferior at depth, a tendency which occurs for all but one subject. Analysis of variance indicated a reliable effect of conditions ($F_{2,10} = 6.4$ $p < .05$). Once again there was no reliable difference between surface and decompression performance, both of which were superior to performance at depth.

16. Sleep Quality and Mood Questionnaires

For the analysis of both sleep quality and mood, data from dive 9 have been omitted. This has been done for two reasons. The first is that in dive 9 the two subjects, commercial divers, only completed one mood questionnaire each day in the morning, whereas in all the other dives the mood questionnaires were completed both in the morning after awakening, and in the evening just prior to going to sleep. The second reason for omitting the dive 9 data is that subjects were reported as having difficulty following instructions for these tasks, resulting in the data appearing somewhat unreliable.

17. Sleep Quality

Figure 11 shows the pattern of subjective sleep quality, as measured by the visual analogue scale item, for all subjects in dives 5, 6, 7 and 8. The graph shows a rapid decline in estimated sleep quality during the compression phase, and indicates a possible tendency for a limited amount of adaptation and improvement in sleep quality beginning just before reaching maximum depth, and continuing through the decompression phase, with rapid recovery of pre-dive levels after the dive is completed. An analysis of variance was performed, comparing the pre-dive sleep quality levels, maximum depth sleep quality levels and sleep quality levels during decompression showed a significant effect of conditions ($F_{2,8} = 11.56$; $p < .01$). Newman-Keuls Range Testing indicated that pre-dive sleep quality was significantly better than both maximum depth sleep quality and decompression sleep quality ($p < .05$), but that there was no significant difference between maximum depth and decompression sleep quality.

18. Mood Questionnaires

Data from all the mood questionnaires were measured and two scores were computed for each questionnaire giving the level of "alertness" felt by the subject at that time, and his level of "tranquility", by combining the various ratings weighted as suggested by Herbert et al (1976).

a. "Alertness" Figure 12 shows the pattern of subjective levels for all subjects in dives 5, 6, 7 and 8. The graph tends to indicate a slight decline in estimated level of alertness, which persists throughout the dives, and a limited amount of recovery after completion of the dives. An analysis of variance showed a significant effect of depth ($F_{2,8} = 7.35$; $p < .025$). Newman-Keuls Testing again indicated that pre-dive levels of alertness were significantly better than both maximum depth and decompression levels of alertness ($p < .05$). and that there was no significant difference between maximum depth and decompression levels of alertness.

Fig. 10. Visual search for 2, 4 or 6 items as a function of dive and condition.

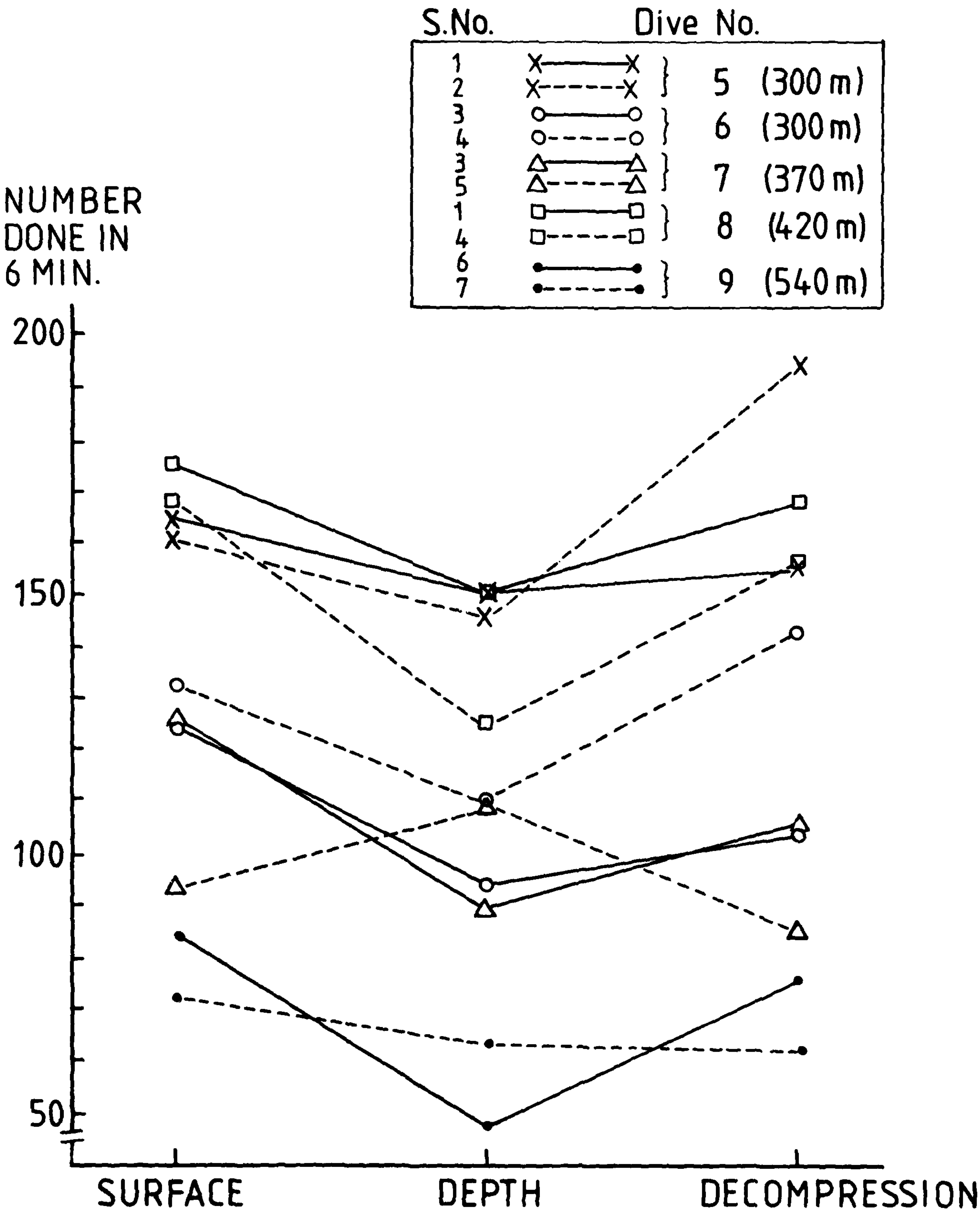


Fig. 11 Rated sleep quality throughout dives 5 to 8.

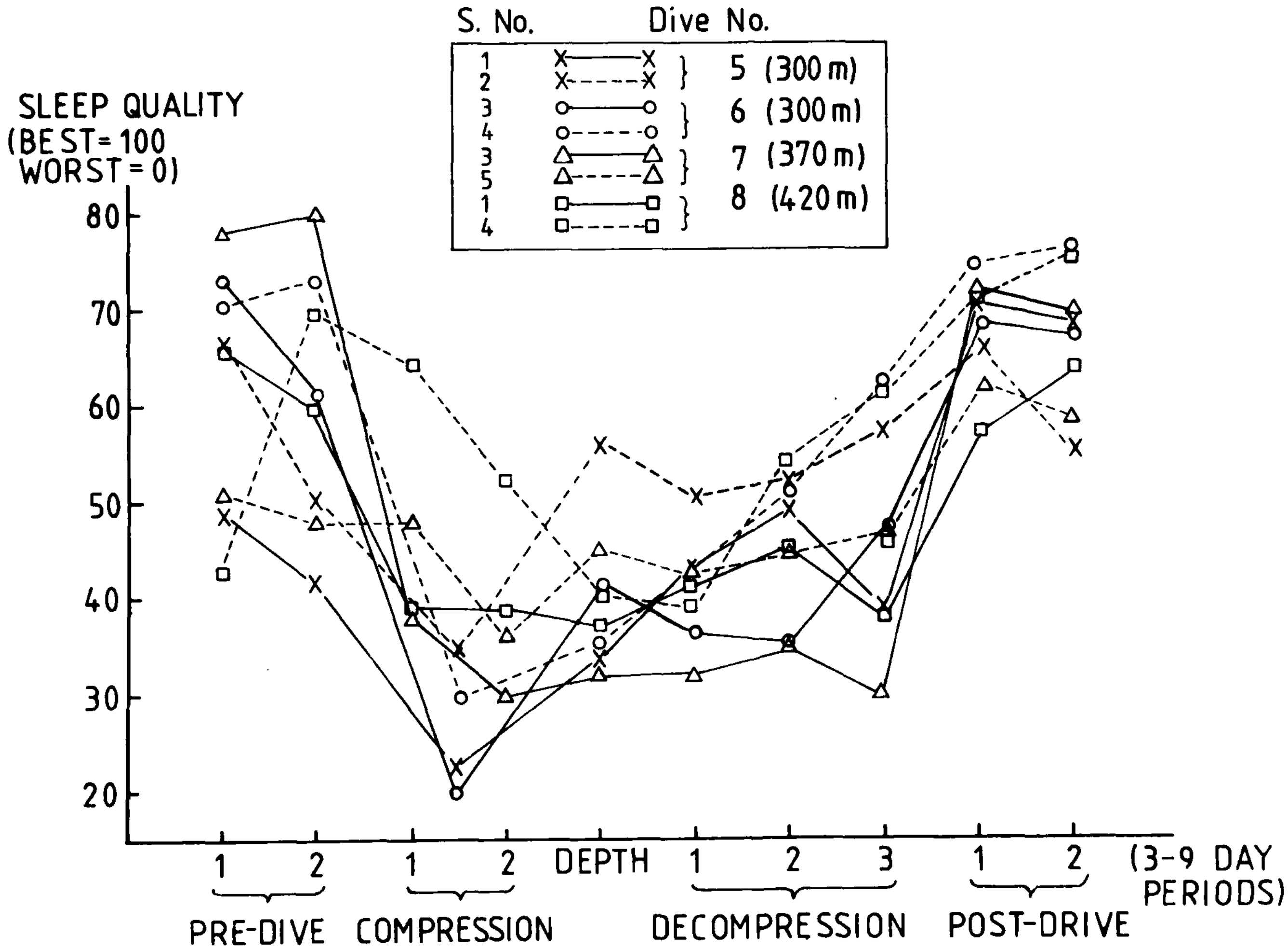


Fig. 12 Subjectively rated alertness throughout dives 5 to 8.

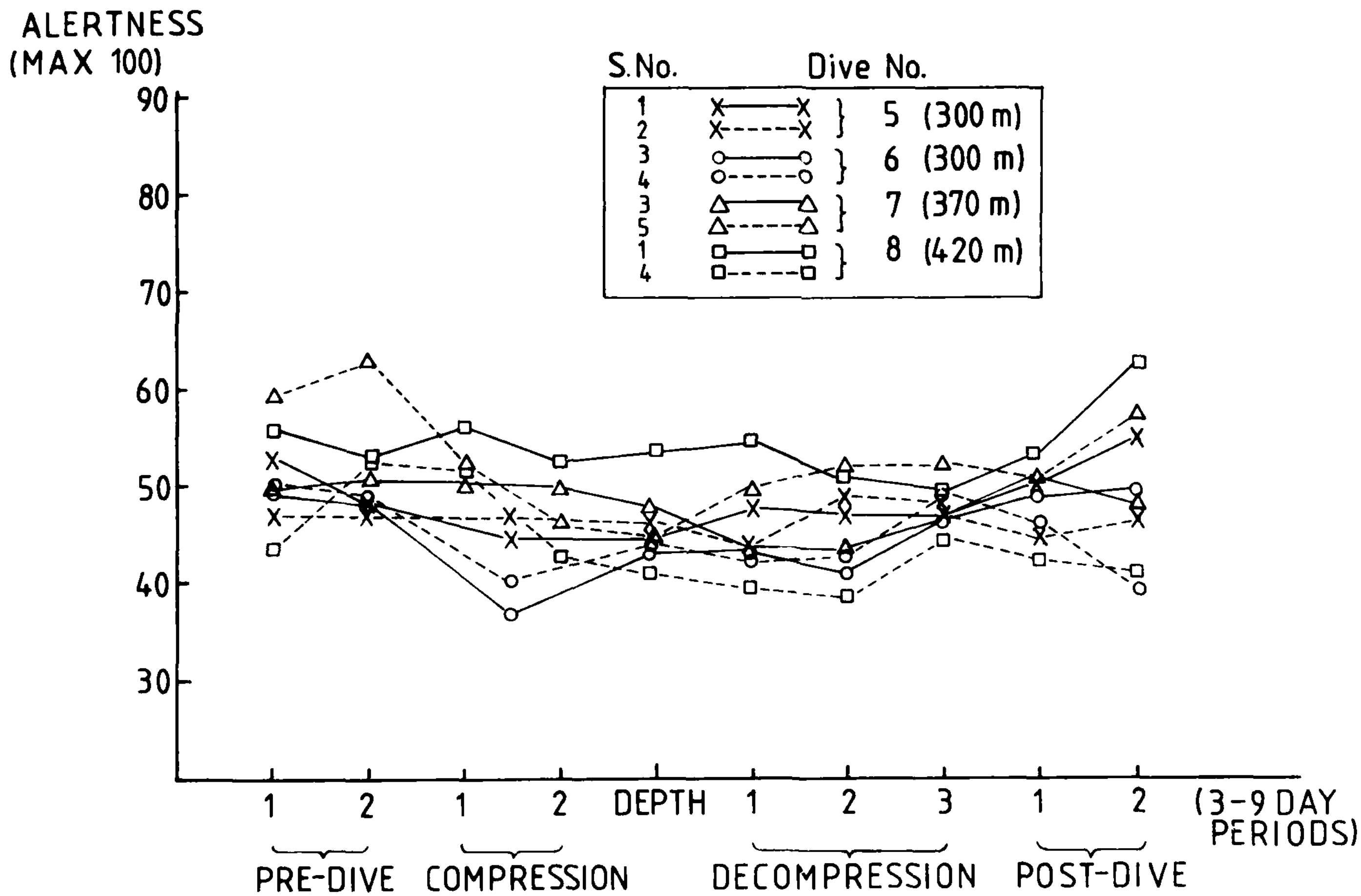
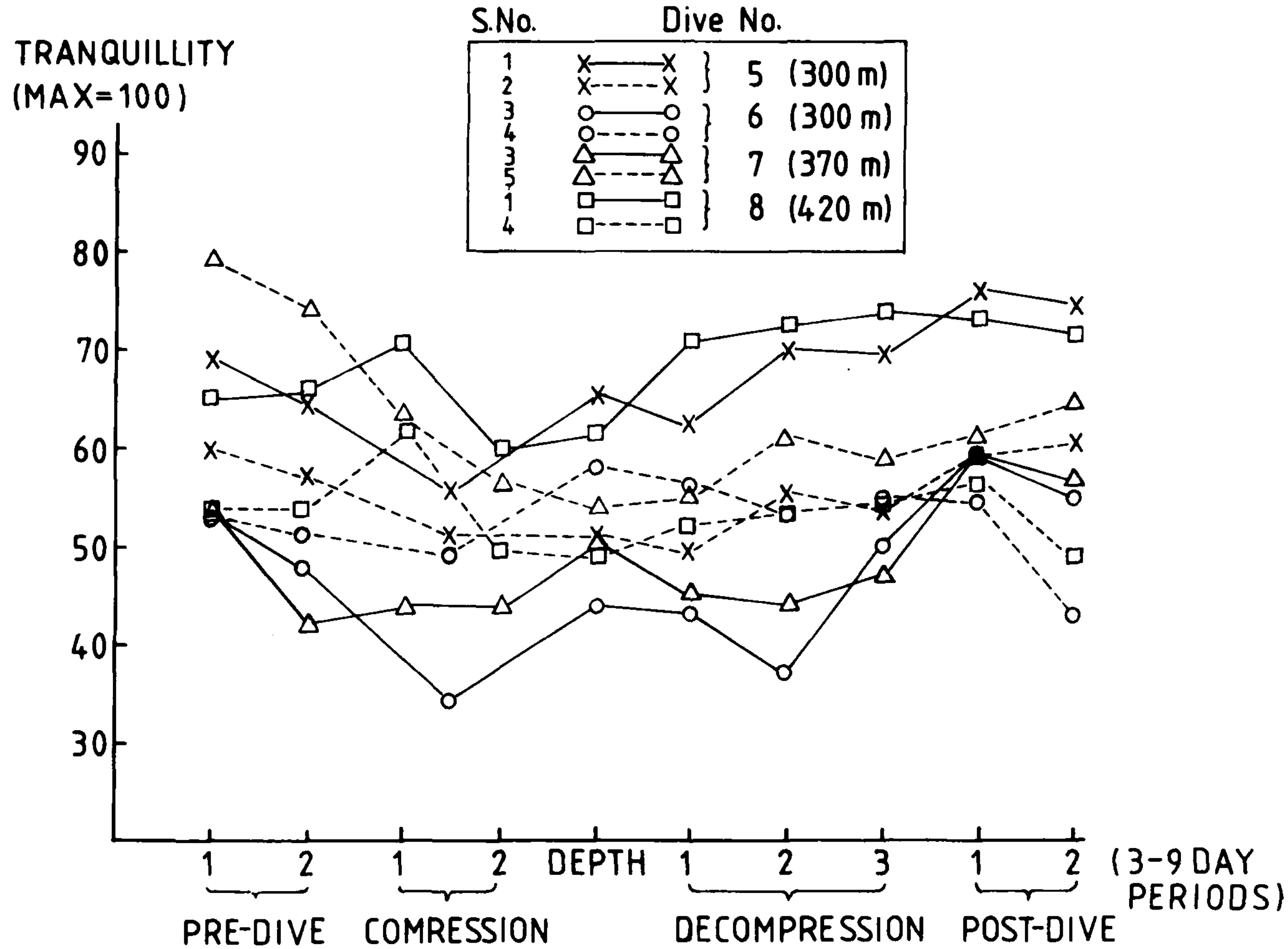


Fig. 13. Subjectively rated tranquility throughout dives 5 to 8.



b. "Tranquility" Figure 13 shows the pattern of subjective levels of tranquility for all subjects in dives 5, 6, 7 and 8. Although the graph appears to suggest a slight decline in estimated levels of tranquility approaching maximum depth, and a tendency to recovery during decompression, an analysis of variance showed no significant effect of depth ($F_{2,8} = 2.80$, $p < .05$).

19. Correlations between Performance, Sleep and Mood

Since similar significant effects were found on the analyses of variance and Newman-Keuls Range Testing, when comparing pre-dive, maximum depth and decompression subjective sleep quality levels, and when comparing pre-dive, maximum depth and decompression levels of alertness, it seemed reasonable to investigate whether there might be any relationship between sleep quality and alertness. The resultant correlation was negative and non-significant ($r = -0.47$, $n = 8$, $p < .05$). Levels of alertness and levels of tranquility were non-significantly correlated ($r = +0.34$, $n = 8$, $p < .05$).

It was then decided to investigate whether there might be any relationships between those performance tests with significant effects, and sleep quality, level of alertness and level of tranquility. Table 2 gives the correlation coefficients (and levels of significance, where appropriate) between the individual performance tests, and sleep quality, alertness and tranquility. With such small numbers, any effects should of course be treated with caution. They can however provide some indication of whether the performance decrements are likely to be attributable to sleep deprivation, loss of alertness or to anxiety.

20. Sleep Quality and Performance

Of 22 correlations, only one achieved significance at the 5% level, namely that between short term memory performance over the last third of the test and rated sleep quality, while the relationship between number similarities and performance just fails to be significant. While such results are plausible, given the sensitivity of a prolonged addition task to sleep deprivation, one would expect one correlation of this level out of 22 on a purely chance basis. Hence, while sleep is impaired at depth, there is no good reason to assume that sleep loss was responsible for the very general and consistent performance impairment observed at depth. Such a conclusion is further reinforced by the observation that sleep quality was little better during decompression than it was at depth, whereas all the 10 measures which show impaired cognitive performance reveal a significant difference between performance at depth and performance on decompression.

21. Cognitive Performance and Subjective Alertness

The pattern of correlations in this case looks somewhat more convincing, with the tasks involving visual search for several items tending to show significant negative correlation with level of alertness. A similar pattern is shown in the case of number similarities which seems to combine a memory load and visual search component. The visual search without memory load shows no significant relationship with level of alertness, implying that it is the combination of search and memory load that is crucial. Such a conclusion is consistent with the observation of this task in conditions of sleep deprivation by Folkard et al (1976). The only other correlation is with percent correct on the last third of the addition task. Since the correlation goes in the opposite direction during the first and second thirds, this result should probably be treated with caution.

Table 2. Correlations between sleep quality, mood and cognitive performance

Performance Test	Sleep Quality	Alertness	Tranquility	N
Adding (items completed)				
1st 1/3	-0.23	-0.60	-0.23	8
2nd 1/3	-0.26	-0.33	-0.24	8
3rd 1/3	-0.28	-0.52	+0.19	8
Adding (% correct)				
1st 1/3	+0.36	+0.25	+0.47	8
2nd 1/3	-0.37	+0.46	+0.70*	8
3rd 1/3	+0.25	-0.67*	-0.34	8
Manikin Figures	+0.20	+0.41	-0.23	6
Stroop Control	+0.28	-0.47	-0.78*	8
Stroop Colour	-0.22	+0.30	-0.14	8
Number Similarities	+0.58	-0.75*	-0.08	8
Semantic Processing	-0.42	-0.03	+0.16	4
Short Term Memory	+0.57	-0.12	+0.11	8
1st 1/3	+0.45	-0.10	+0.06	8
2nd 1/3	+0.41	-0.22	+0.09	8
3rd 1/3	+0.64*	-0.06	+0.13	8
Visual Search "O"	-0.41	-0.29	-0.04	8
V.S. 2, 4 & 6 (sum)	+0.19	-0.80*	-0.57	8
V.S. 2 (only)	-0.08	-0.65*	-0.08	8
V.S. 4 (only)	+0.45	-0.73*	-0.73*	8
V.S. 6 (only)	+0.04	-0.52	-0.46	8
Sleep	-	-0.47	-0.43	8
Alertness	-	-	+0.34	8

* $p < .05$

22. Cognitive Performance and Rated Tranquility

This shows three significant correlations, none of which is easy to interpret. A significant positive correlation between percent correct and rated tranquility occurs in the adding test, but only for the middle third of the test; the correlation is indeed in the opposite direction for the final third. A second correlation occurs in the case of the Stroop control condition. It seems unlikely that this can provide an adequate explanation for the performance data however since clear performance decrements occurred for both the control and colour conditions, whereas tranquility appears to be quite unrelated to Stroop colour performance. Finally a significant correlation occurs for visual search, but only when the subject is holding four items, not when the load is two or six. Again this bears little relationship to the pattern of results in observed performance. Bearing in mind therefore the scattered and inconsistent nature of the correlations observed with tranquility, together with the absence of a significant difference in rated tranquility between depth and decompression, it seems highly unlikely that our clearly observed performance decrements at depth can be accounted for in terms of anxiety.

23. Between-dive Differences

The dives have ranged in depth from 300 m to 540 m, and it would obviously be highly desirable to plot a series of dose-response curves showing the effect of depth on the various cognitive tasks. Unfortunately, for a number of reasons our present data do not allow this. First of all, with a relatively small pool of subjects there is likely to be an inevitable confounding between subjects and depths. The situation is further complicated by the fact that some subjects took part in one dive, some in two, but in the case where a subject was tested twice, he inevitably made the shallower dive first, hence confounding test order with depth. Yet another complication is introduced by the fact that the deepest dive was carried out by professional divers whose general background, attitudes and motivations were different from those likely to occur in the subjects participating in earlier dives, all of whom were AMTE/PL staff.

Despite these obvious limitations however, since diving data of this sort are so expensive and difficult to obtain we decided to look for inter-dive differences. We did so using analysis of variance and looking for an interaction between dive number and conditions. By looking for such interactions rather than main effects, we would be less likely to pick up spurious differences between dives based entirely on differences in baseline performance between the different divers. This analysis yielded four significant interactions, namely speed of addition ($F_{8, 10} = 4.05$, $p < .05$), accuracy of addition ($F_{8,10} = 9.41$, $p < .001$), speed of performance on the Stroop colour tests ($F_{8,10} = 7.10$, $p < .01$) and speed of semantic processing ($F_{4,6} = 8.23$, $p < .05$). While it would be unwise, for the reasons just outlined, to draw any firm conclusions from these interactions, they do suggest that any subsequent study attempting to plot dose response curves for breathing oxyhelium at pressure would do well to include addition, the Stroop test and semantic processing within its test battery.

DISCUSSION

24. Results from the performance tests in this series of dives clearly show that there is indeed a significant impairment in many aspects of cognitive functioning when oxyhelium is breathed at depths exceeding 300 msw. Significant impairment was shown on all but two of the tests, paired-associate memory and verbal reasoning.

In the case of the paired-associate task, there was indeed a non-significant tendency for performance to be better at depth, a result which is consistent with the absence of a decrement in associative learning observed by Biersner and Cameron (1970 a) and O'Reilly (1977); Carter (1979) even found improved performance at depth, and it could be objected that our results are limited by the fact that half our subjects were scoring at a level of 100% when at depth. Clearly if this test is to be used in the future it will prove necessary to include more than four pairs of items. From a practical viewpoint, this task seems to imply that subjects are as able to learn as well at pressure as on the surface; unfortunately it seems unlikely that learning new material will form a particularly large proportion of the commercial diver's job at depth.

The second task to show no effect of depth on efficiency is the grammatical reasoning test. It is interesting that this should be resistant to the effects of pressure since it is clearly a relatively complex and demanding test which has been shown to correlate with intelligence and to be sensitive to a number of stresses, including that of nitrogen narcosis (Baddeley, 1968; Baddeley, de Figuerado, Hawkswell Curtis and Williams, 1978). It is however becoming clear that this task is quite selective in its sensitivity since it is also resistant to the effects of alcohol (Baddeley, in press; Strong, personal communication). In general, the fact that at least two of our tests show a clear absence of performance decrement is encouraging since it implies that the effects of pressure when breathing oxyhelium are not produced by a simple blanket impairment in all cognitive performance. As such it suggests that it should be possible to produce specific impairment profiles, with different environmental stressors producing a different profile of impairment. Such profiles should then prove useful both in analysing mode of action of the stressor and also in using stress as a means of further understanding normal cognitive processing.

The remaining tests all show impairment at depth to a greater or lesser extent. The decrement in speed and accuracy of addition resembles the drop in arithmetic performance shown by Carter (1979) and the drop in accuracy shown by O'Reilly (1977) and is probably related to the decrement in the number ordination task studied by Lemaire and Murphy (1976). Hence, although Hamilton (1976) did not find an impairment in multiplication, the balance of the evidence clearly suggests that arithmetic ability will be impaired at depths exceeding 300 msw. The manikin figures test can be assumed to be a measure of spatial manipulation, that is "the ability to identify, orient, to transform and visually explore spatial configurations" (French, Ekstrom and Price, 1963). O'Reilly (1977) found no significant impairment on a card rotation task in hyperbaric conditions, although a subsequent covariance analysis taking into account fatigue, anxiety and mood self-reports did indicate a trend towards performance loss in the spatial manipulation task. This trend is confirmed in the present study, with the poorest performance occurring at depth.

Performance on both the Stroop and the Stroop control tests show comparable degrees of decrement at depth. This suggests a general impairment in perceptual speed rather than a particular susceptibility to conflict. As such, it is consistent with Biersner (1970 a) who found no evidence of increased Stroop interference at a pressure approximately equal to 300 m of sea water.

The semantic processing test is relatively new, and apart from being shown to be affected by alcohol (Baddeley, in press) has not been so far tried by other investigators. It appears to be highly sensitive to the effects of depth, implying as it does that a diver's access to the knowledge he has acquired will be slower when he is operating at depths exceeding 300 m.

Both the short term memory and number similarities tasks place demands on immediate memory, and the fact that both are somewhat impaired suggests that pressure will influence short term memory performance. The number similarities result confirms that observed by Carter (1979).

The impairment in visual search again suggests a decrement in perceptual processing speed, similar to that observed by O'Reilly (1974). In general, the pattern shown for the visual search task did not depend on whether the subject was searching for two, four or six items, therefore suggesting that the pattern of decrement is quite different from that observed by Folkard et al (1976) in a study on the effect of the time of day on performance. This supports the conclusion drawn from the mood and sleep ratings that decrements in cognitive performance were not attributable to lower alertness at depth.

In conclusion, our results suggest that though a diver is quite able to function at the depths studied, his cognitive efficiency is likely to be impaired on a wide range of tasks. He is also likely to suffer from partial sleep deprivation, and a possible drop in alertness. It seems highly unlikely that either of these is responsible for the observed performance decrements however, since sleep is no better during decompression that it is at depth, while performance recovers to a pre-dive level. The observed decrement in cognitive performance is likely to have important implications for both his efficiency and safety under open sea conditions.

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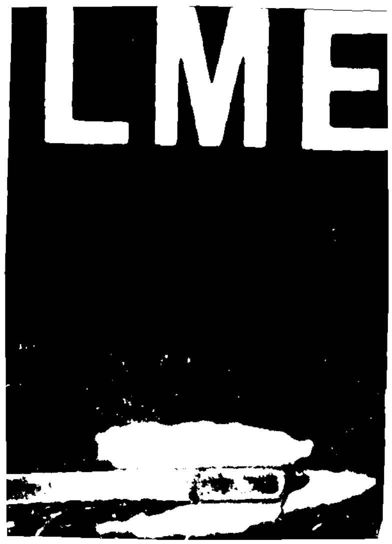
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